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(2)

ANALYSIS OF RUNWAY OCCUPANCY TIME AND SEPARATION DATA COLLECTED AT LA GUARDIA, BOSTON, AND NEWARK AIRPORTS

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16. Abstract
This document analyzes arrival runway occupancy times, separation, and interarrival time data collected in July 1984 at New York La Guardia and Boston Logan airports. Runway occupancy time data collected in December 1983 at Newark airport is also included in the study. The data collection effort was undertaken by FAA's Terminal Procedures Branch, AAT-320 (with technical support from ADL-5) to obtain baseline reference data at a busy airport operating a single arrival stream under the current separation standards.

In addition to the summary data, means, standard deviations, and the number of observations are included for statistics on the three types of data collected. These are broken down by aircraft type (Small, Large, and Heavy), by runway at each airport, and, for La Guardia, by weather condition (VMC and IMC). Also, a comparison is made of runway occupancy times in wet- versus dry-runway conditions.

Additional keywords: data reduction; weather, tables (data); Stewart flight ...

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EXECUTIVE SUMMARY

The possibility of reducing longitudinal separations during Instrument Flight Rules (IFR) approaches has been under investigation for many years. A rigorous analysis of the requirements was performed by The MITRE Corporation in 1979 (Reference 2). This led to the most recent recommendation which came from the Industry Task Force on Capacity and Delay led by Airport Operators Council International. This was a proposal to reduce the longitudinal separation to 2.5 nautical miles (nmi) when wake vortices are not a factor. In response to that recommendation, Federal Aviation Administration's (FAA) Air Traffic Service has initiated an implementation program. This report resulted from a collaboration between the Terminal Procedures Branch (AAT-320) and the Office of System Studies and Cooperative Programs (ADL-5) to obtain baseline data in support of the demonstration program which is now underway.

Runway Occupancy Times (ROTs), arrival separations, and Interarrival Times (IATs) were collected at New York La Guardia and Boston Logan airports in July 1984. In addition, ROT data collected by the FAA in December 1983 at Newark airport are included in this study. Information was also collected at Boston and La Guardia on go-arounds, particularly those necessary to avoid simultaneous runway occupancy.

Approximately 600 observations were collected at each of the three airports. At La Guardia, 132 observations were collected for operations on wet runways during Instrument Meteorological Conditions (IMC). The data base itself represents a potential resource for future studies of runway use. Observations at these three airports may not necessarily be indicative of operations at other airports because exit locations, aircraft types, runway lengths and surface conditions all vary. In addition, the data do not represent a statistically valid random sample of nationwide operating characteristics.

The following statistics summarize the results of the data collection effort.

1. The overall average ROTs (in seconds) for the three airports were:

Aircraft Type	LGA	BOS	EWR
Small	43.5	48.7	40.1
Large	46.0	52.1	42.2
Heavy	50.5	56.7	45.6

The higher ROTs at Boston are attributable to the closure of a critical exit (for repairs) on the main arrival runway.

2. Average ROTs (in seconds) under wet and dry conditions were:

Runway Condition	LGA	BOS
Dry	45.5	51.5
Wet	47.1	51.1

Note that both the wet and dry average ROTs at La Guardia are less than 50 seconds. The similarity in the ROTs at Boston may be a result of the closure of a critical exit.

3. The average separation at the threshold between pairs of Large aircraft (which account for three-fourths of all observations) at La Guardia was 3.2 nmi in Visual Meteorological Conditions (VMC). This increased to 3.6 nmi in IMC.

Because a single stream of arrivals fed more than one runway at Boston, the separation and IAT data do not represent a busy-arrivals situation. Hence, they are not summarized but are included in the detailed tables for completeness.

4. In VMC at La Guardia, 36.4 percent of all arrivals were separated by less than 3.0 nmi; 21.9 percent were separated by less than 2.5 nmi. In IMC, including pilot-applied visual separations, 18.0 percent of all arrivals were separated by less than 3.0 nmi while 7.8 percent were separated by less than 2.5 nmi.

5. The average IAT between Large aircraft pairs at La Guardia was 104 seconds in VMC. This increased to 112 seconds in IMC.

These observations imply that:

1. Separations of 2.5 nmi seem to be both useful and feasible.

2. Reduced separations are useful for absorbing arrival peaks and for runway configurations where departures can be easily interwoven, such as arrivals on runway 22 and departures on runway 13 at La Guardia.

3. There are potential capacity gains in IMC at airports such as La Guardia from operating at reduced longitudinal separations.

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1. INTRODUCTION AND BACKGROUND

Due to recent, dramatic increases in delays to aircraft at major airports, concepts for increasing airport capacity have gained impetus (Reference 1). These studies are also in response to the near-impossibility of building new runways at these airports, the traditional solution to the capacity problem. One of these concepts is the reduction of the minimum longitudinal separation between certain classes of aircraft on final approach (Reference 2).

Reduction of the minimum longitudinal separation has been considered for the past 15 years. After a large increase in delays in 1968, the Air Traffic Control Advisory Committee (ATCAC) advocated the reduction of longitudinal separation in the terminal area from 3.0 to 2.0 nautical miles (nmi). However, with the introduction of widebody aircraft, the Federal Aviation Administration (FAA) was forced to increase, rather than decrease, some separations due to wake vortex considerations. Although the minimum separation remained 3.0 nmi, separations were increased for all aircraft following Heavy aircraft (greater than 300,000 lbs. Gross Takeoff Weight, (GTOW)), and for Small aircraft (less than 12,500 lbs. GTOW) following Large aircraft (greater than 12,500 lbs. and less than 300,000 lbs. GTOW).

A rigorous study of the requirements for reducing the minimum longitudinal separation to 2.5 nmi and 2.0 nmi was performed by The MITRE Corporation in 1979 (Reference 2). It concluded that, if the wake vortex problem could be resolved, a reduction to 2.5 nmi would be possible if the average runway occupancy times were below 50 seconds.

In 1982, an Industry Task Force on Airport Capacity Improvement and Delay Reduction was formed under the guidance of the Airport Operators Council International. Its mandate was to advise the Federal Aviation Administration on "the most promising and practical improvements or changes that FAA should implement at congested airports that make sense from an operational perspective". Its members include representatives from the aircraft industry, the military, aviation user groups, academia, airport operators, and airport engineers. The Task Force reported on its suggested improvements in September 1982. These included a specific suggestion to reduce minimum longitudinal separation on final approach to 2.5 nmi for aircraft pairs where wake vortex is not a problem.

In 1984 the FAA's Terminal Procedures Branch (AAT-320) initiated an implementation program designed to demonstrate the feasibility of using 2.5 nmi separations. The first step in that program was a joint effort between the Office of System Studies and Cooperative Programs (ADL-5) and AAT-320 which resulted in this report describing the current operations at three major airports.

1.1 Motivation for Data Collection

The data collection effort was motivated by a study (Reference 2) evaluating the potential for a reduction of the minimum longitudinal separation on final approach (currently 3.0 nmi). Since simultaneous runway occupancy by most aircraft types is prohibited, it was felt that a study of current runway occupancy times was necessary to be certain that simultaneous runway occupancy would not be a problem if the minimum separation was reduced. In addition, the effort was undertaken to provide baseline data on the operations at a busy airport.

There has been concern that 2.5 nmi separations between arrivals may not leave gaps large enough to interleave departures where the departure stream is dependent on the arrival stream. While in some cases this may be true, the purpose of reducing longitudinal separations on final approach is to produce an increase in capacity during an arrival peak or for runway/operational configurations where departures can be easily interwoven with arrivals. To help assess the impact of reduced arrival separations on departures, this study also analyzes the arrival separations and departure flows in the present situation.

Since reducing longitudinal separation could influence the rate of go-arounds necessary to avoid simultaneous runway occupancy by two arrivals, go-arounds (and the reasons for them) were closely observed. Finally, since there is in general a lack of good information on these characteristics, it seemed prudent to collect them when the opportunity arose. Some of the other data gathered were: departure runway occupancy times, separations currently in effect, interarrival time values, the presence of moisture on the runway, and arrival-departure interaction in a crossing-runway situation. All of these factors are detailed in this report.

1.2 Scope and Purpose

The purpose of the data collection effort was to obtain baseline data on separations and runway-use statistics under the current operating rules at busy airports. Apart from the collection of the data itself, the study also included reduction of the data: resolving conflicting values found on the data-collection forms, translating the data into a format suitable for analysis, and the generation of useful statistics, such as means, standard deviations, and frequency distributions, through a computer-based statistical package.

2. DATA COLLECTION EFFORT

Runway Occupancy Time (ROT), longitudinal separation, and Inter-arrival Time (IAT) data were gathered at La Guardia and Boston Logan airports (Figures 2-1 and 2-2) during July 1984 by FAA and MITRE personnel. ROT data only were gathered at Newark (EWR) (Figure 2-3) in December 1983 by FAA observers for the Port Authority of New York and New Jersey. The Newark data were then supplied to this study in a partially-reduced form.

2.1 Data Collection Procedures at La Guardia and Boston

There were three observers at all times: one to obtain data on arrival separation using the tower's Bright Radar Indicator Terminal Equipment (BRITE) display, one to observe arrival runway occupancy times, and one to observe departure runway occupancy times. At La Guardia (LGA), all three observers were stationed in the air traffic control tower. At Boston Logan (BOS), however, one observer was in the tower while the other two occupied a location near the tower from which all runways and exits were visible. At both locations all time values were obtained using digital watches which were synchronized to the time readout visible on the tower's BRITE display. Also at both locations, the observer recording the departure data monitored the local controller's voice radio frequency. Weather information was collected from the Automatic Terminal Information Service (ATIS) and from wind indicators located on the airfield surface.

2.2 List of Data Items Collected

2.2.1 La Guardia and Boston

The following data items were collected at LGA and BOS.

1. Arrival Runway Occupancy Time Data.

    a. Aircraft Type;

    b. Airline and Flight number (when applicable);

    c. Time Over Threshold;

    d. Time Clear of Runway;

    e. Exit Number (Location);

    f. Other Runway Use (i.e., by taxiing or departing aircraft);

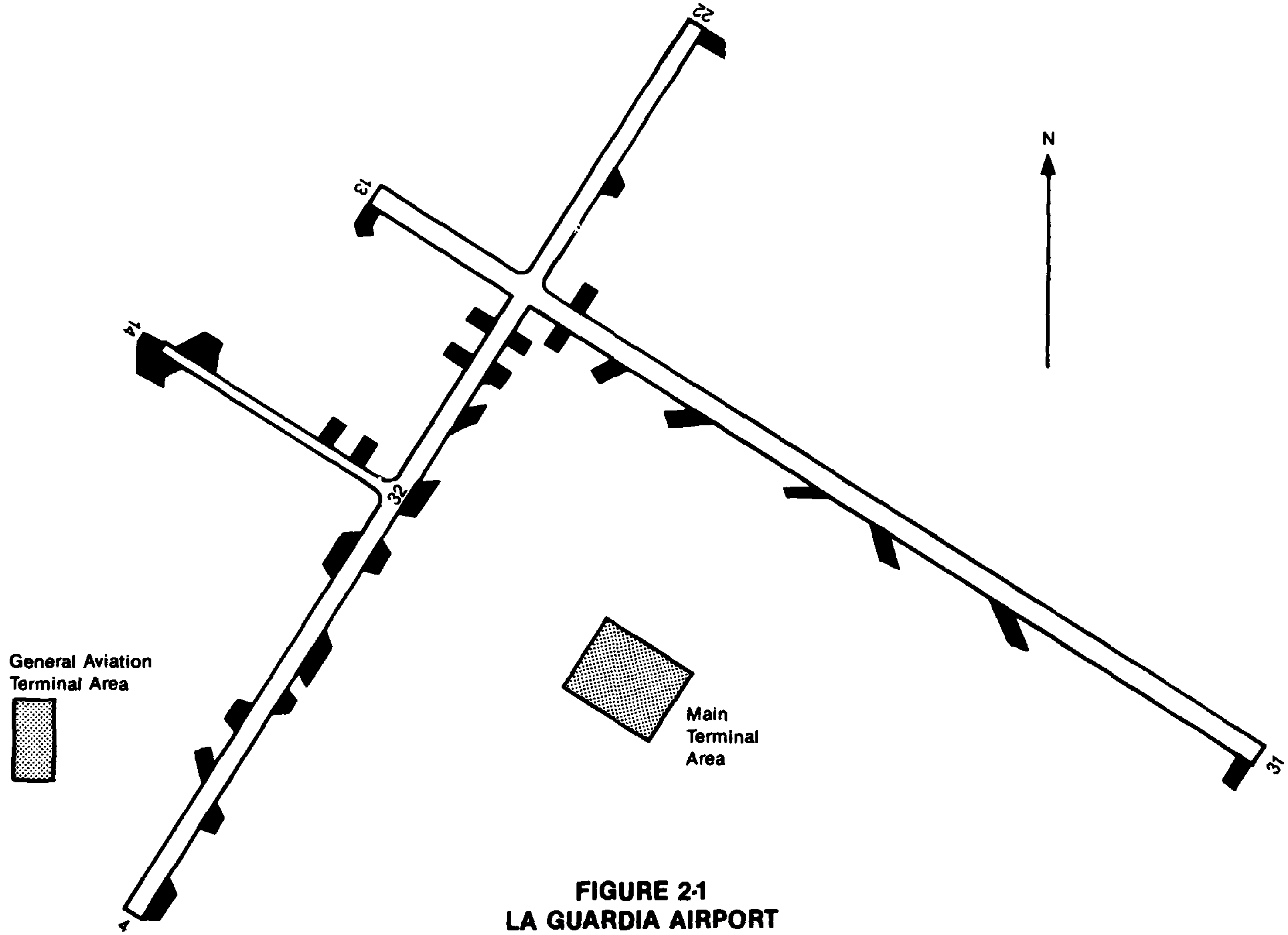

FIGURE 2-1
LA GUARDIA AIRPORT

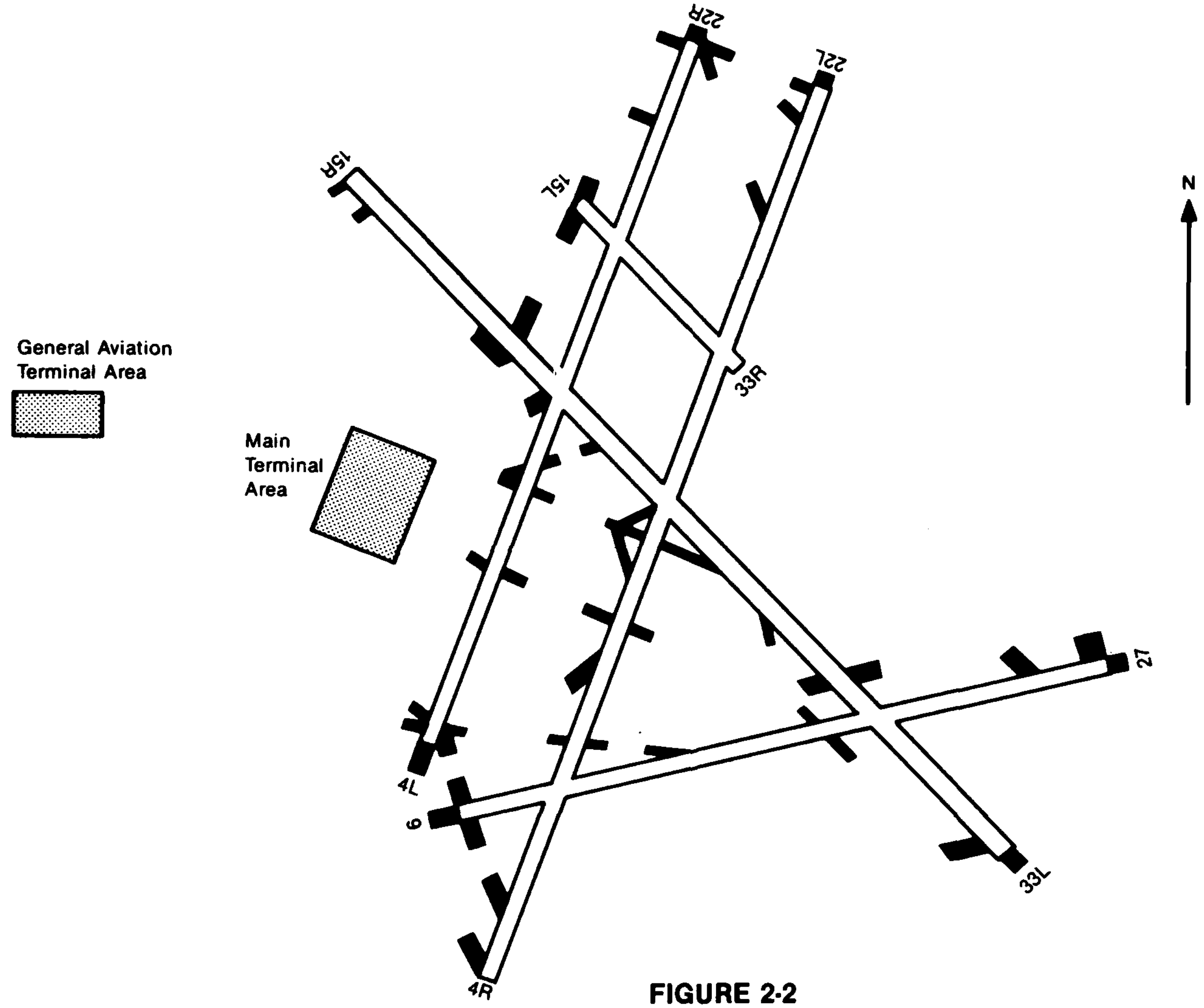

FIGURE 2-2
BOSTON LOGAN INTERNATIONAL AIRPORT

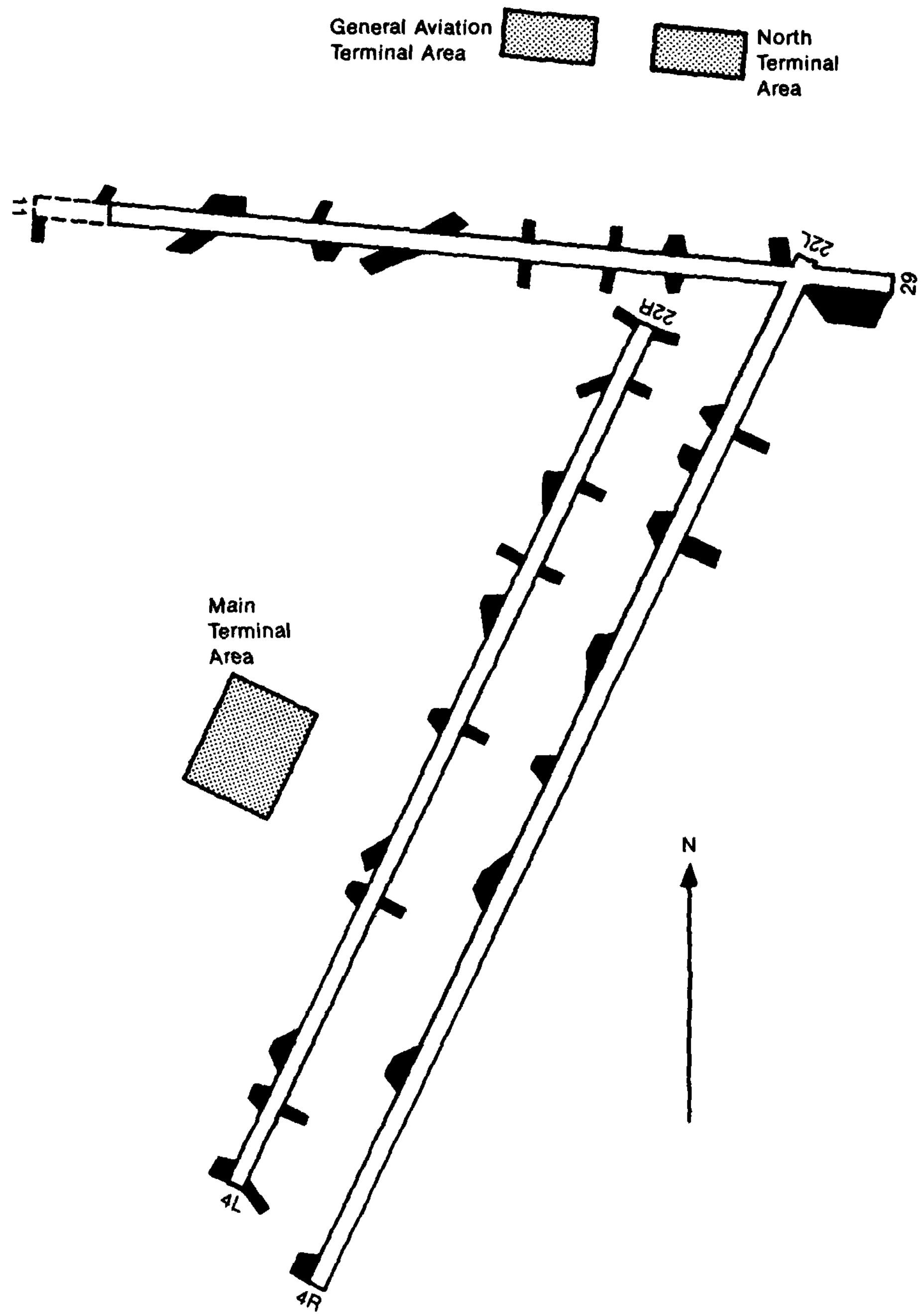

FIGURE 2-3
NEWARK INTERNATIONAL AIRPORT

g. Runway Number; and

h. Comments (anything pertaining to the runway use or conditions).

2. Arrival Separation Data.

a. Aircraft Type (leading aircraft);

b. Airline and Flight Number;

c. Separation Distance;

d. Time Over Threshold (leading aircraft);

f. Runway Number; and

g. Comments.

3. Departure Runway Occupancy Time Data.

a. Aircraft Type;

b. Time Cleared onto Runway;

c. Time Cleared for Takeoff;

d. "Wheels up" Time;

e. Departure Held for Crossing Aircraft (yes/no);

f. Departure Held for Arrival on Same Runway (yes/no); and

g. Comments.

4. Additional Data (taken by all observers).

a. Date;

b. Airport;

c. Starting Time;

d. Flight Rules in Effect;

e. Runway Condition (Wet or Dry);

f. Arrival Runways in Use;

g. Departure Runways in Use;

h. Ceiling and Visibility; and

i. Wind Speed and Direction.

The duplication of important data between observers allowed correlation between separation and ROT data and supplied missing values. (See Figures 2-4 through 2-6 for samples of the data collection sheets.)

2.2.2 Newark

The Newark data, as supplied in its reduced form, consists solely of runway occupancy times, broken down into the number of occurrences of each individual ROT for each aircraft class/runway/exit combination.

2.3 Difficulties in Data Collection

There were difficulties associated with the collection of the aircraft's threshold-crossing time and time clear of the runway. These had to be estimated visually from the control tower. The distance from the tower to the threshold varied from one-fourth to one mile and the angle from which the arrival was observed over the threshold varied as well. Thus the observer had to find a consistent reference to estimate the point at which the aircraft was exactly over the threshold, and this point of reference undoubtedly varied between observers.

The accuracy of the longitudinal separations between aircraft was limited. These were estimated using the 1 nmi gradations on the final approach course shown on the BRITE display in the tower. Thus the accuracy of these estimates was limited by the observer's ability to estimate distances on the display and the accuracy of the terminal radar. Given the combination of these factors, the distances are estimated to be accurate to plus or minus one-fourth of a nautical mile.

Separations greater than 10 nmi did not appear on the BRITE display due to range limitations. Thus these separations could not be recorded and were marked "no traffic" in the data.

Some separation data also was not recorded due to operational difficulties: when a single stream of arrivals fed more than one runway (as was the case at Boston), aircraft on final approach

Page___ IFR_VFR_
Date__/__/__ WET_DRY_

ZULU Time__:__:__
HH:MM:SS

RUNWAY OCCUPANCY TIME DATA (ARRIVALS)

MAIN ARRIVAL RUNWAY____________

Airport_____

CEILING____________
VISIBILITY__________
WIND DIRECTION_____
WIND SPEED_________

Check (✓) if runway used for crossing by taxiing or departure from crossrunway after this arrival

Arriving Aircraft Type & Flight #		Time Over Threshold MM:SS	Time Off Runway MM:SS	Exit Number	Other Use	Comments: Anything that would effect ROT or data collection effort
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			
		:	:			

FIGURE 2-4
DATA COLLECTION FORM FOR
ARRIVAL RUNWAY OCCUPANCY TIME DATA

SEPARATION DATA (ARRIVALS)

Page___ IFR_VFR_ ARRIVAL RUNWAY______________
Date__/__/__ WET_DRY_ Other runways in use: Arrival____________
Airport_____ Departure__________
ATIS_________
ZULU Time__:__:__
HH:MM:SS

CEILING____________
VISIBILITY__________
WIND DIRECTION_____
WIND SPEED_________

Arriving Aircraft Type & Flight #		Separation Distance	Time of Observation (MM:SS)	Comments: note any event related to separation (e.g. significant weather affecting visibility, aborted approaches, vortex encounter, wind shear, speed restrictions, etc.)
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	
			:	

FIGURE 2-5
DATA COLLECTION FORM FOR SEPARATION DATA

RUNWAY OCCUPANCY TIME DATA (DEPARTURES)

Page___ IFR_VFR_
Date__/__/__ WET_DRY_
Airport_____
ATIS______
ZULU Time__:__:__
HH:MM:SS

ARRIVAL RUNWAY IN USE______________

CEILING__________
VISIBILITY________
WIND DIRECTION_____
WIND SPEED________

Check (✓) if true

Departing Aircraft Type	Time Cleared on Runway	Time Cleared for Takeoff	Time Clear of Main Runway	Held For Xing A/C	Held For Arr.	Comments:
	:	:	:			
	:	:	:			
	:	:	:			
	:	:	:			
	:	:	:			
	:	:	:			
	:	:	:			
	:	:	:			
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	:	:	:			
	:	:	:			

FIGURE 2-6
DATA COLLECTION FORM FOR
DEPARTURE RUNWAY OCCUPANCY TIME DATA

were often directed out of the arrival stream to a runway other than the main arrival runway. Thus, separation between aircraft was lost.

In addition, from the standpoint of observer workload, when multiple arrival runways were in use, some operations on secondary runways were missed entirely to ensure the accuracy of the data gathered for the main runway. In effect, it was found that one observer could accurately collect only one type of data (arrival, departure, or separation) for only one runway.

3. DATA REDUCTION

Following the collection, the data were entered into computer files, erroneous items were corrected or deleted, and additional values were computed and entered into each record. The goal in the data reduction effort was that each record be correct and complete unto itself.

3.1 Data Reduction Process

The data reduction process consisted of translating every item on the data-collection sheets into computer-readable information and then encoding it in a flexible format. Since some of the values, such as general information on weather and operating conditions and over-the-threshold time, were recorded by more than one observer, cross-checking of some of the information was possible and missing values were minimized. Many questionable observations had to be discarded while many incomplete but sound ones were retained; these decisions were made on a case-by-case basis. Also, in the many instances of conflicting values, one value had to be chosen over another based on knowledge of the source and the situation at the time of its recording. This process was performed for approximately 1200 data records for arrivals alone. The departure data were not reduced for this study.

The weather data and other general information were originally recorded on separate records in the computer data files. These were then removed and the information written to each individual record by a Formula Translater Programming Language (FORTRAN) program. Any missing values in a data record were marked as such so that the statistical package would ignore them and yet use the remaining data in the partial record. In this way maximum usage of the data recorded was achieved.

Finally, additional values were calculated for each operation by a FORTRAN program. These values included the ROT, computed by subtracting the over-the-threshold time from the exit time, and the IAT, computed by subtracting the over-the-threshold time from that of the following arrival on that runway. These values were then inserted into each record.

3.2 Data Recorded

Each data record includes all of the information about each operation. Items recorded specifically for each arriving aircraft were:

1. Aircraft type;

2. Airline identifier (where applicable);

3. Separation in nmi between this and the trailing aircraft;

4. Time over the runway threshold;

5. Time clear of the runway (exit time); and

6. Exit used.

Items pertaining to conditions that were in effect at that time were:

1. Airport identifier;

2. Date;

3. Ceiling;

4. Ceiling Type (e.g., Overcast, Broken);

5. Visibility;

6. Obstructions to Vision (e.g., Rain, Fog);

7. Wind Direction; and

8. Wind Velocity.

The following values were computed and inserted into each record of arrival data:

1. Runway Occupancy Time;

2. Interarrival time (between current and following aircraft);

3. Next aircraft type to land on runway following current aircraft; and

4. Trailing aircraft type against which separation was measured.

3.2.1 La Guardia Arrival Data

The data gathered on arrivals at La Guardia were generally considered to be consistent, accurate, and depicting a situation where pilots were able to leave the runway after landing with no constraints and onto well-placed exits.

3.2.2 Boston Arrival Data

The arrival data at Boston were, unfortunately, not as good, for the following reasons.

1. A single stream of arrivals fed more than one arrival runway. This meant that after separation was measured between two arrivals the trailing aircraft occasionally was diverted to another runway. The effects of this were:

    a. Separation information was often lost, particularly during conditions when arrival demand was not heavy.

    b. Interarrival times were inordinately large for each runway.

    This resulted in the dilemma that, in the data base, the separation and interarrival time recorded for an arrival might in fact be measured against two different trailing aircraft.

2. Runway 15L/33R was closed for repairs. Under normal conditions, this runway is used as a very desirable exit by large aircraft leaving runways 4L and 4R. The closure resulted in abnormally high runway occupancy times for large aircraft using these runways.

3. Arrivals on runway 27 were directed to exit at the far end of that runway, also increasing average ROTs.

Thus, the ROTs for Boston were judged to be abnormally high, while IATs and separations were not correlated with each other and thus not representative of the actual situation. The problem with IATs and separations was resolved by manually determining for each case which aircraft was the trailing aircraft from both an interarrival time standpoint and a separation standpoint. Knowledge of the Air Traffic Control (ATC) procedures used at Boston coupled with the fact that the same personnel both observed and analyzed the data made this possible. It can be stated, then, that the separations and IATs recorded in the data base are accurate and representative of the true situation at Boston. However, many observations were discarded in the reduction process and, since arrival demand at Boston was often not high, the IAT and separation values cannot be said to represent a peak-arrival situation. The data on runway occupancy times is representative of the actual operations, but could be reduced by use of existing taxiways.

3.2.3 Newark Arrival Data

Unfortunately, there was less information available for Newark. The raw data, as submitted to this study, consisted solely of frequency counts of individual ROTs (e.g., 43 seconds - 12 observations, 44 seconds - 10 observations, etc.) for a given aircraft class on a given runway, leaving that runway on a given exit. There was no interarrival time information nor separation data. The reduction of the Newark data consisted of generating means, standard deviations, and frequency distributions for the ROT data.

3.3 Weather Conditions

3.3.1 La Guardia Weather Conditions

The data for LGA were collected over a period of 4-days, July 18th through the 20th and July 23rd (all weekdays). The observers gathered data from 7:30 am until 12:30 pm each day. On the first day, the ceiling was 600 feet (broken) with visibility at 2-miles in light to heavy rain. Braking conditions on the wet runways were good. Occasionally, poor braking conditions were reported, but these reports were never substantiated by the pilot of the following aircraft.

The remaining days were all Visual Meteorological Conditions (VMC) with dry runways. Thus approximately one-fourth of the LGA data is true Instrument Meteorological Conditions (IMC) data recorded while wet runways were in use.

3.3.2 Boston Logan Weather Conditions

The Boston data were also collected over four weekdays, on July 26th, 27th, 30th, and 31st. However, on the first 2 days the data were collected in the morning (7:30 am until 12:30 pm), while on the final 2 days the data were gathered from 2:30 pm until 7:30 pm. On all 4 days at Boston the weather was VMC, but on 1 day a light rain fell, producing wet runways. The braking conditions were comparable to those of La Guardia's wet runways.

3.3.3 Newark Weather Conditions

The data for Newark were gathered under VMC with dry runways.

3.4 Data Classification

Table 3-1 displays the number of observations, broken down by weather condition, aircraft type, runway condition, and runway. La Guardia had the largest percentage of Large aircraft and also the only IMC data collected. Also, from this chart, it can be seen that 84 percent of Boston's operations were on runways 4L/R and 27; hence, the tremendous impact on ROTs of the closure of runway 15L/33R and the ATC directive to exit runway 27 at its far end. Further information on the data, including means, standard deviations, and frequency distributions, can be found in the following chapter.

TABLE 3-1
DATA CLASSIFICATION

	Boston Logan		La Guardia		Newark	
Operations	No.	Percent	No.	Percent	No.	Percent
Total	617	100.0%	587	100.0%	551	100.0%
VMC	617	100.0	421	71.7	551	100.0
IMC (<1000,3)	0	0.0	166	28.3	0	0.0
Small Aircraft	120	19.4	33	5.6	116	21.0
Large Aircraft	420	68.1	499	85.0	394	71.5
Heavy Aircraft	77	12.5	55	9.4	41	7.5
Dry Runways	479	77.6	455	77.5	551	100.0
Wet Runways	138	22.4	132	22.5	0	0.0
Boston Runway:						
4L	127	20.6				
4R	252	40.8				
22L	88	14.3				
27	150	24.3				
La Guardia Runway:						
4			77	13.1		
22			351	59.8		
31			159	27.1		
Newark Runway:						
22L					172	31.2
22R					30	5.5
29					349	63.3

4. DATA ANALYSIS

The data were analyzed using the Statistical Package for the Social Sciences, which is an integrated system of computer programs designed for the statistical analysis of data. The use of this package allowed not only the generation of general statistics describing the data collected, but also the extraction of individual:

1. Means;

2. Standard Deviations;

3. Number of Observations; and

4. Frequency Distributions.

4.1 Runway Occupancy Times

The overall average ROTs (in seconds) for arrivals at the three airports were:

Aircraft Type	LGA	BOS	EWR
Small	43.5	48.7	40.1
Large	46.0	52.1	42.2
Heavy	50.5	56.7	45.6

Note, once again, that the higher average ROTs at Boston are attributable to the preferred exit closure and the ATC directive. (See Chapter 3 for details.)

For La Guardia and Boston, both wet and dry ROTs were available. The overall averages were (in seconds):

	LGA	BOS
Dry	45.5	51.5
Wet	47.1	51.1

Note that the wet and dry values were very close. Analysis showed that there was no statistically significant difference between the wet and dry average ROTs at Boston. However, this may have been a result of the closure of a preferred exit. Note that both the wet and dry average ROTs at La Guardia were less than 50 seconds.

Figures 4-1 through 4-3 illustrate the distribution of ROTs for Small and Large aircraft in bar-chart format. (The distributions for these aircraft are displayed because they represent the vast majority of the operations observed.)

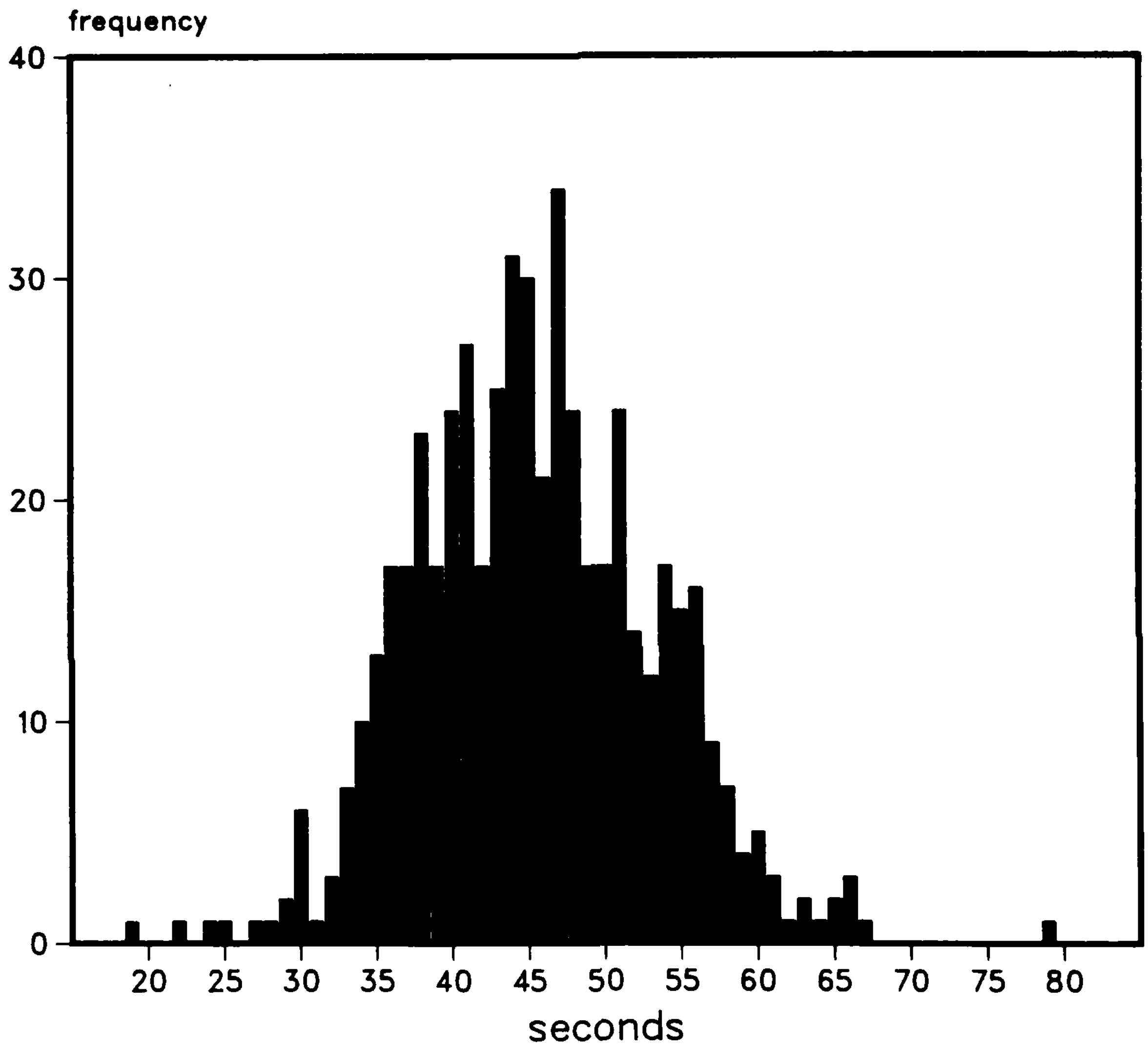

FIGURE 4-1
LGA RUNWAY OCCUPANCY TIME DISTRIBUTION
SMALL AND LARGE AIRCRAFT
(ROTs GREATER THAN 80 SECONDS NOT DISPLAYED)

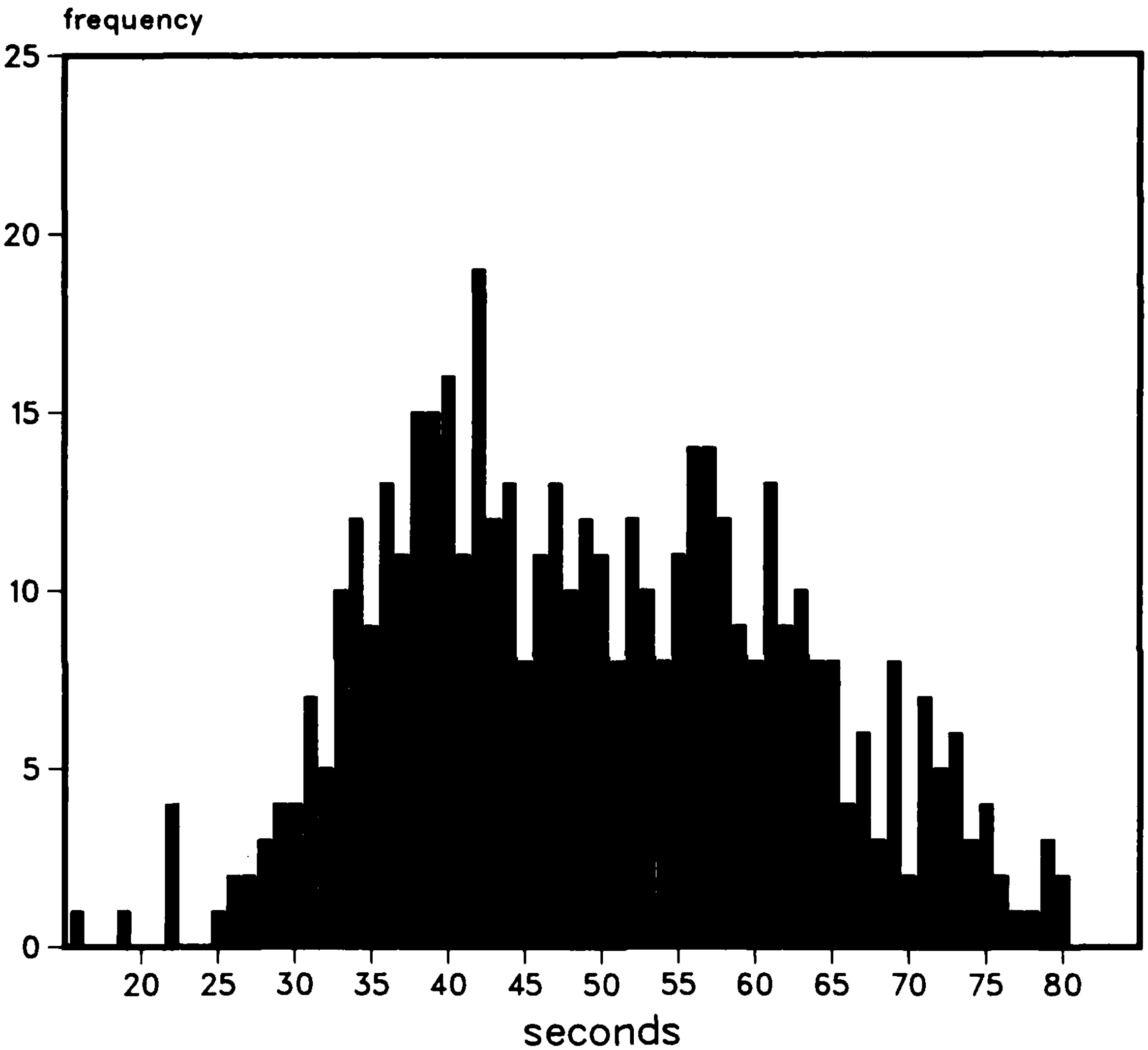

FIGURE 4-2
BOS RUNWAY OCCUPANCY TIME DISTRIBUTION
SMALL AND LARGE AIRCRAFT
(ROTs GREATER THAN 80 SECONDS NOT DISPLAYED)

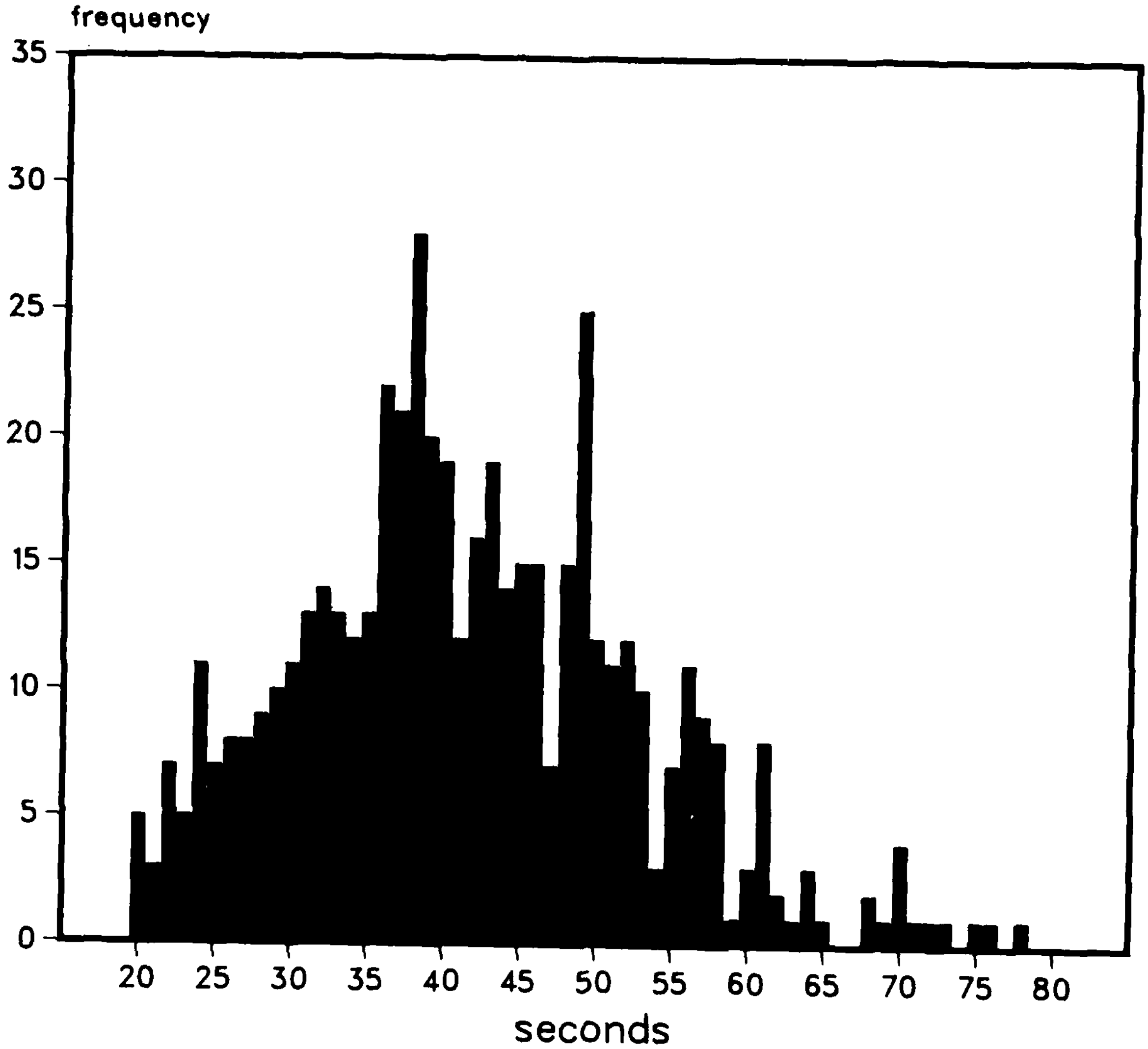

FIGURE 4-3
EWR RUNWAY OCCUPANCY TIME DISTRIBUTION
SMALL AND LARGE AIRCRAFT
(ROTs GREATER THAN 80 SECONDS NOT DISPLAYED)

The following tables present the mean, standard deviation, and number of observations for each category. In each "box" in the table, the number of observations is shown on the top line, the mean value is shown at the lower left, and the standard deviation is shown at the lower right. Tables 4-1, 4-3, and 4-5 display the average ROTs for each aircraft type on each runway under all conditions for LGA, BOS, and EWR, respectively. Tables 4-2 and 4-4 display the average ROTs for each aircraft type in both wet- and dry-runway conditions for LGA and BOS, respectively.

4.2 Separation Data

Table 4-6 presents a summary of the average separations during IMC and VMC between aircraft pairs on final approach at LGA (in the same format as that used for ROTs). Figure 4-4 displays the separations at LGA between pairs of Large aircraft in both IMC and VMC. Again, Large aircraft were chosen because they represent the majority of all aircraft pairs.

In VMC, 36.4 percent of all arrivals were separated by less than 3.0 nmi and 21.9 percent were separated by less than 2.5 nmi. In IMC, including pilot-applied visual separations, 18.0 percent of the separations for all arrivals were less than 3.0 nmi, while 7.8 percent were less than 2.5 nmi. Note, also, that separations between Large aircraft (which account for 73 percent of all separations observed) increased by an average of 0.4 nmi from VMC to IMC.

The use of separations of less than 3.0 nmi under visual conditions is an indication of the feasibility of reducing longitudinal separations. Whether the use of the closer separations is to absorb an arrival peak in a period of low departure demand or with a runway configuration where departures can be interleaved, it is sometimes advantageous and feasible to do so.

Because of the problems cited in Chapter 2, the data from Boston were determined to be nonrepresentative of actual separations during peak-arrival conditions. The results were therefore not presented in the summary but the details (for VMC only) were included for completeness in Table 4-7.

TABLE 4-1
LA GUARDIA
AVERAGE RUNWAY OCCUPANCY TIMES
(GROUPED BY AIRCRAFT SIZE)

Runway	Aircraft Size: 5.6% Small		85.0% Large		9.4% Heavy		100% Total	
22	19		301		31		351	
	45.3	9.9	46.8	8.2	52.5	9.6	47.2	8.5
4	3		65		8		76	
	39.7	7.2	47.9	10.2	52.7	7.6	48.1	10.1
31	11		132		16		159	
	41.6	11.0	43.4	10.6	45.2	5.1	43.5	10.2
Total	33		498		55		589	
	43.5	10.0	46.0	9.3	50.5	8.8	46.3	9.3

Number Of Arrivals
Mean ROT (seconds) Std. Dev. of ROT (seconds)

TABLE 4-2
LA GUARDIA
AVERAGE RUNWAY OCCUPANCY TIMES VS RUNWAY CONDITION

Runway Condition	Small		Large		Heavy		Total	
VMC/Dry	28		383		44		455	
	44.5	9.7	45.6	9.1	50.4	9.2	46.0	9.3
IMC/Wet	5		115		11		131	
	37.8	10.8	47.5	9.5	50.6	7.4	47.4	9.5

Number Of Observations
Mean ROT (seconds) Std. Dev. of ROT (seconds)

TABLE 4-3
BOSTON
AVERAGE RUNWAY OCCUPANCY TIMES
(GROUPED BY AIRCRAFT SIZE)

	Aircraft Size							
	17.9%		68.9%		13.2%		100%	
Runway	Small		Large		Heavy		Total	
22L	26		55		5		86	
	67.7	21.1	51.5	14.9	53.6	14.5	56.6	18.4
4R	13		174		43		230	
	45.7	11.8	52.7	12.1	53.7	10.7	52.5	11.9
4L	55		61		0		116	
	40.6	13.5	44.5	18.3	NA	NA	42.7	16.2
27	6		95		26		127	
	47.3	11.7	56.2	15.8	62.2	12.6	57.0	15.3
Total	100		385		74		559	
	48.7	19.2	52.1	15.0	56.7	12.2	52.1	15.6

Number Of Observations
Mean ROT (seconds) Std. Dev. of ROT (seconds)

TABLE 4-4
BOSTON
AVERAGE RUNWAY OCCUPANCY TIMES VS RUNWAY CONDITION

Runway Condition	Small		Large		Heavy		Total	
VMC/Dry	71		303		62		436	
	40.0	20.0	51.9	15.5	56.1	12.8	52.2	16.1
IMC/Wet	29		82		12		123	
	45.7	16.8	53.0	12.7	59.5	8.1	51.9	13.9

Number Of Observations
Mean ROT (seconds)   Std. Dev. of ROT (seconds)

TABLE 4-5
NEWARK
AVERAGE RUNWAY OCCUPANCY TIMES
(GROUPED BY AIRCRAFT SIZE)

Runway	Aircraft Size: 21.0% Small		71.5% Large		7.5% Heavy		100% Total	
22R	10		16		4		30	
	43.6	9.9	50.0	9.8	49.0	5.2	47.7	9.6
22L	36		123		13		172	
	47.2	9.8	48.8	8.3	49.3	10.0	48.5	8.7
29	70		255		24		349	
	36.1	10.0	38.6	7.5	43.1	5.3	38.4	8.1
Total	116		394		41		551	
	40.1	11.1	42.2	9.3	45.6	7.6	42.1	9.7

Number Of Arrivals	
Mean ROT (seconds)	Std. Dev. of ROT (seconds)

Source: FAA For Port Authority of New York and New Jersey (PANYNJ)
(Based On Reduced Data Supplied By FAA)

TABLE 4-6
LA GUARDIA SEPARATIONS* - VMC VS IMC

VMC

Lead	Trail Small		Large		Heavy	
Small	2		19		2	
	2.2	0.4	2.6	1.0	3.0	0.0
Large	18		264		26	
	3.0	1.1	3.2	1.3	3.7	1.4
Heavy	2		31		8	
	3.5	2.1	3.8	1.2	4.5	2.5

IMC

Lead	Trail Small		Large		Heavy	
Small	0		7		0	
	NA	NA	3.0	1.3	NA	NA
Large	6		122		10	
	3.1	0.6	3.6	1.2	4.4	1.9
Heavy	1		8		0	
	5.0	0.0	4.9	0.8	NA	NA

Number Of Observations	
Mean Separation (nmi)	Std. Dev. of Separation (nmi)

* Includes Only Separations of 10 nmi And Less.

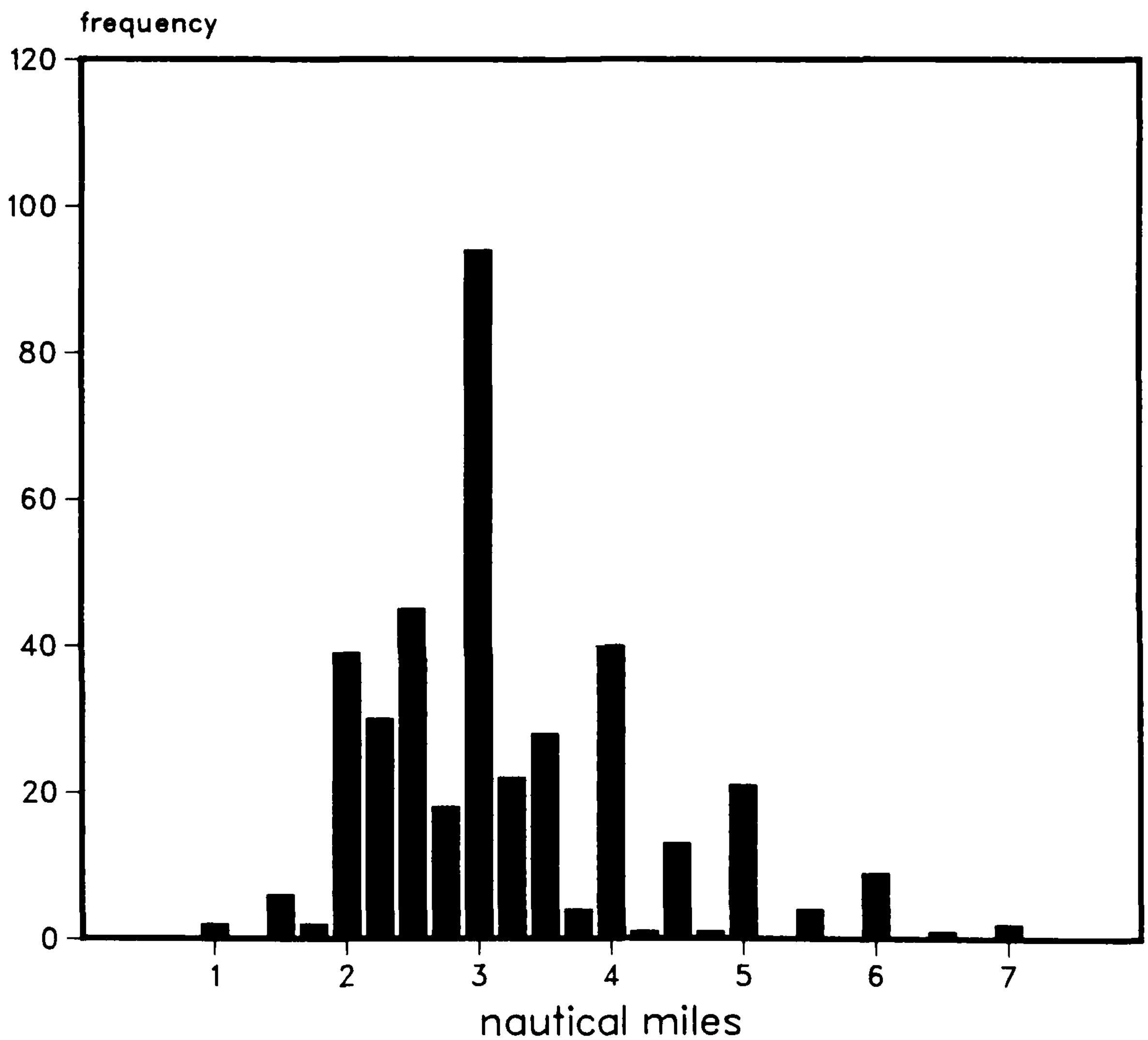

FIGURE 4-4
LGA LONGITUDINAL SEPARATIONS
LARGE FOLLOWING LARGE AIRCRAFT
(SEPARATIONS ABOVE 7.0 NMI NOT DISPLAYED)

TABLE 4-7
BOSTON
AVERAGE LONGITUDINAL SEPARATIONS*

Lead	Trail: Small		Trail: Large		Trail: Heavy	
Small	7		17		2	
	2.7	1.2	3.5	1.1	4.5	2.1
Large	20		149		45	
	2.9	1.4	3.6	1.1	3.8	1.1
Heavy	6		37		4	
	4.4	0.7	4.0	0.8	4.0	2.0

Number Of Observations
Mean Separation (nmi)   Std. Dev. of Separation (nmi)

* Includes Only Separations 10 nmi And Less.

4.3 Interarrival Times

Table 4-8 presents a summary of IATs for La Guardia in both VMC and IMC. Figure 4-5 presents a frequency distribution in bar-chart format of IATs for pairs of Large aircraft.

Once again, because the IATs did not represent busy-arrival conditions, the IATs for Boston were not included in the summary. However, the details can be found (for VMC only) in Table 4-9.

4.4 Arrival and Departure Interaction

When surveying separation and IAT values, it is important to keep in mind that at both Boston and La Guardia there was considerable interaction between arrivals and departures during peak periods.

During the busiest hour (which occurred in VMC) at each airport the following distribution was observed:

	LGA	BOS
Average number of arrivals	34.8	41.0
Average number of departures	35.0	32.0

The averages for La Guardia are representative of a true intersecting-runway situation. For all runway operating configurations observed there, the vast majority of all departures were released on the runway which intersected the arrival runway.

In Boston, however, departures were consistently released on more than one runway but recorded only for the main departure runway. For example, referring to Figure 2-2, when the primary arrival runway was 22L, departures were released on both runway 15R and runway 22R. The average number of departures shown above, then, included only those departures from runway 15R and therefore underestimated the actual number of departures released.

The above figures imply, then, that at La Guardia and Boston, a departure was almost always released (on an intersecting runway) between two arrivals.

4.5 Go-Arounds and Missed Approaches

In this study, a "missed approach" is an approach that is aborted due to ceiling/visibility conditions below the stated minima while a "go-around" is an approach that is aborted for any other reason.

TABLE 4-8
LA GUARDIA
INTERARRIVAL TIMES* - VMC/DRY VS IMC/WET

VMC/Dry

Lead	Trail: Small		Trail: Large		Trail: Heavy	
Small	2		20		2	
	69.0	12.7	79.2	27.5	81.0	4.2
Large	18		287		31	
	95.1	35.2	104.3	46.4	124.8	41.8
Heavy	2		32		8	
	106.0	58.0	108.1	23.2	113.7	47.9

IMC/Wet

Lead	Trail: Small		Trail: Large		Trail: Heavy	
Small	0		8		0	
	NA	NA	100.2	43.6	NA	NA
Large	7		125		11	
	121.4	70.3	112.4	43.5	137.1	61.4
Heavy	2		8		0	
	203.5	38.9	131.4	57.4	NA	NA

Number of Pairs
of Arrivals
Mean IAT (seconds) Std. Dev. of IAT (seconds)

*Excludes All Observations Above 300 Seconds (3% Of Observations).

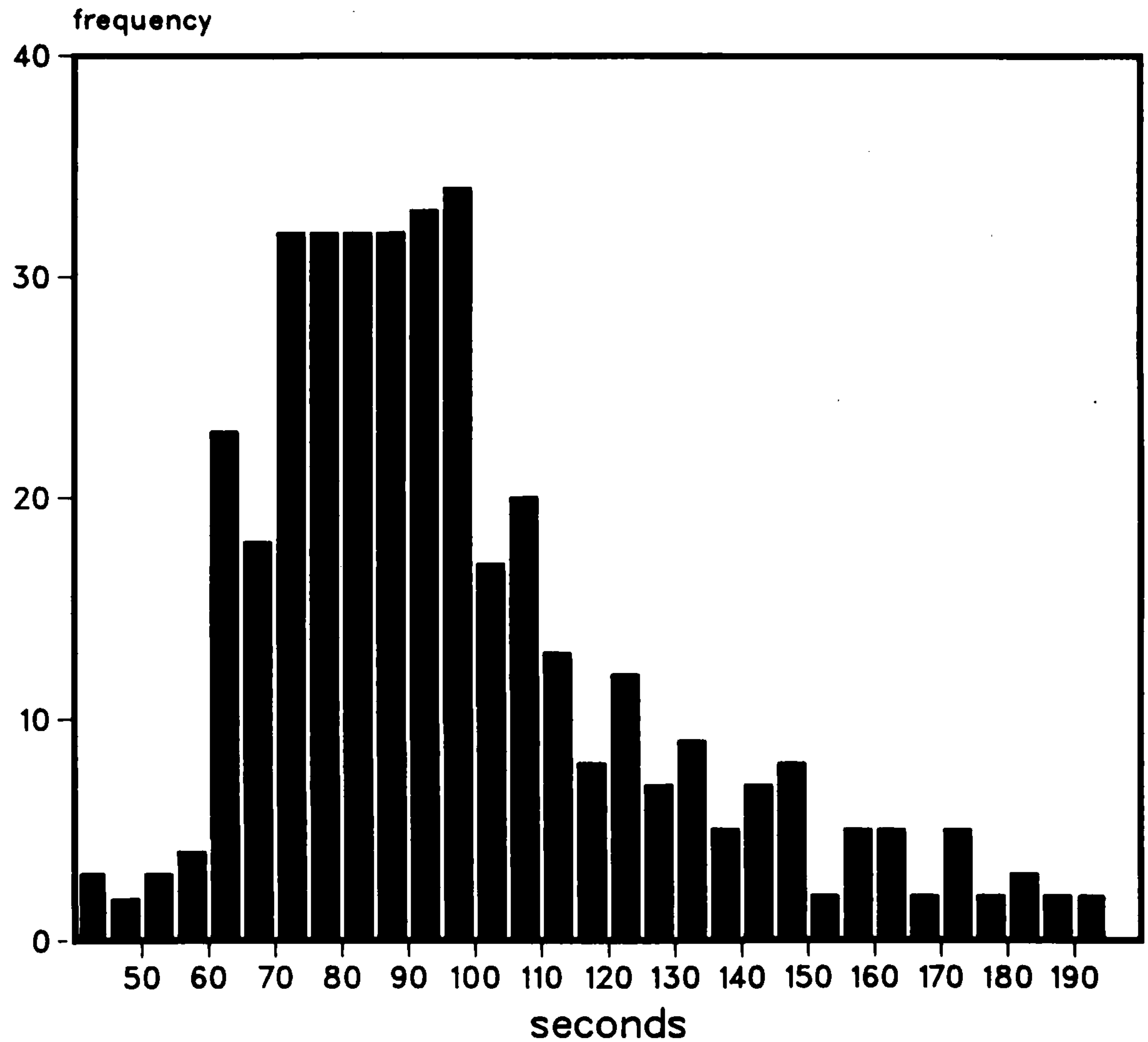

FIGURE 4-5
LGA INTERARRIVAL TIMES
LARGE FOLLOWING LARGE AIRCRAFT
(IATs ABOVE 200 SECONDS NOT DISPLAYED)

TABLE 4-9
BOSTON
INTERARRIVAL TIMES*

Lead	Trail: Small			Trail: Large			Trail: Heavy		
	Number Of Observations	Mean IAT (seconds)	Std. Dev. of IAT (seconds)	Number Of Observations	Mean IAT (seconds)	Std. Dev. of IAT (seconds)	Number Of Observations	Mean IAT (seconds)	Std. Dev. of IAT (seconds)
Small	25	141.6	71.2	49	123.7	56.7	5	99.2	35.9
Large	51	140.7	65.2	240	131.4	59.6	52	121.9	53.8
Heavy	8	142.2	50.1	56	142.8	58.9	4	111.5	41.2

Number Of Observations
Mean IAT (seconds) Std. Dev. of IAT (seconds)

* Excludes All Observations Above 300 Seconds (15% Of Observations).

A small number of go-arounds and no missed approaches were observed at both La Guardia and Boston. At LGA, four go-arounds were observed among 587 arriving aircraft; at BOS, three go-arounds were observed among 619 arrivals.

Two of the four go-arounds at La Guardia were due to impending separation violations. In these cases, two or three arrivals came close to each other (longitudinally). The trailing or center aircraft was then pulled out of the sequence and instructed to go around by the controller. The other two go-arounds at La Guardia were approaches aborted due to obstructions on the runway. In one case, an automobile blocked the runway. In the second case, the runway was obstructed by the tail section of a departing Boeing 767 which was crossing the active arrival runway while taxiing to the departure runway. The B767 was unable to clear the arrival runway completely due to taxiway gridlock, which was caused by taxiways jammed with departing aircraft waiting to take off. Thus there were no go-arounds due to simultaneous runway occupancy.

At Boston, two of the go-arounds were due to potential separation violations similar to those at La Guardia and they were handled in the same manner. However, the third go-around was invoked by the control- ler to avoid simultaneous runway occupancy. A DC9 was recorded as being 3.0 ($\pm$ 0.25) nmi behind a Hawker-Siddeley HS25 business jet as the HS25 crossed the threshold of runway 4R. Due to the closure of the exit provided by runway 15L/33R, the HS25 was forced to leave the runway at the following exit, taxiway "R". This resulted in a runway occupancy time of 79 seconds, thus forcing the DC9 to go around to avoid simultaneous runway occupancy.

5. SUMMARY AND CONCLUSIONS

5.1 Runway Occupancy Times

The average ROTs for Small and Large aircraft at La Guardia and Newark were 46 seconds or less. At Boston, arrivals averaged 52.1 seconds or less on the runway. However, the higher averages were a result of the closure of a preferred exit on one runway and the ATC directive to use the full length of another. We can conclude from the study, then, that ROTs under heavy-traffic conditions with well-placed exits tend to be 46 seconds or less.

5.2 Wet Versus Dry ROTs

Wet runway conditions were observed at both Boston and La Guardia. A comparison of ROTs in wet versus dry conditions revealed a very slight difference of 1.6 seconds between them. This leads us to believe that, although the presence of moisture on the runway may have an effect on braking conditions, it is not the sole determining factor of stopping distance.

5.3 Longitudinal Separations

Observations at La Guardia showed that Large aircraft on final approach in VMC were separated by an average of 3.2 nmi. This increased to 3.6 nmi in IMC. These values support the theory detailed in the reduced longitudinal separations study (Reference 2) that controllers space aircraft at the minimum plus a given buffer, the size of which increases in IMC. That buffer was found to increase, then, by about one-half nmi.

It should also be noted that, in VMC, separations of less than 3.0 nmi were observed 36.4 percent of the time at La Guardia, while 21.9 percent of the separations observed were less than 2.5 nmi. In IMC, including pilot-applied visual separations, 18.0 percent of the separations were less than 3.0 nmi; 7.8 percent were less than 2.5 nmi. This implies that:

1. 2.5 nmi separations seem to be both useful and feasible.

2. Reduced separations are useful for absorbing arrival peaks and for runway configurations where departures can be easily interwoven, such as arrivals on runway 22 and departures on runway 13 at La Guardia.

3. There are potential capacity gains in IMC at airports such as La Guardia from operating at reduced longitudinal separations.

5.4 Interarrival Times

The average IAT between Large aircraft in VMC was observed to be 104 seconds; this increased to 112 seconds in IMC. It should be pointed out that the variation in IATs was larger than expected, even at La Guardia, where the arrival demand was constant for nearly the entire observation period. During the hour in which the greatest number of Large arrivals was observed at La Guardia, the standard deviation for IATs between pairs of Large aircraft was 34.3 seconds. (The mean IAT between these aircraft pairs was 95.9 seconds.) This was observed in VMC. There were 30 Large arrivals in that hour out of 37 arriving aircraft in total. The large variability in IATs was due to the large variability in separations. The source of this variability is not known for certain; it could be due to the effect of departures (on the intersecting runway) on the arrival stream, or it could be due to the inability of the current system to deliver arrivals at precisely the minimum separation.

In order to estimate the standard deviation of IAT for a stream of arrivals, each separated by 3.0 nmi or less, all cases of Large (behind Large) aircraft for which the separation was 3.0 nmi or less were examined and the standard deviation was found to be 15.3 seconds. By selecting only those separations of 3.0 nmi or less, much of the variability has been eliminated so that this does not represent the variability of a system attempting to space aircraft at the minimum separation. It can, however, be thought of as a lower bound for this variability. This observation agrees, then, with the 18 seconds in a previous study (Reference 2) which modelled aircraft spaced at the minimum.

APPENDIX A
INPUT DATA FORMAT

Table A-1 presents a detailed description of the contents of each record in the data base of information on arrivals. The item letters refer to the indicators in Figure A-1.

The format of the data as it was used by the statistical program can be seen in Figure A-1. The compact form of the data reflects both an effort to keep data records to 80 characters or less and an effort to keep as many values as possible numerical rather than alphabetical. This was done to reduce the Central Processing Unit (CPU) time necessary to execute the statistical package; otherwise the program converted all alphabetical data to numerical each time it executed.

TABLE A-1
DEFINITIONS OF DATA BASE ITEMS

Item	
a	Airport Identifier L - New York La Guardia B - Boston Logan
b	Day of the month on which the item was recorded
c	Arrival Runway
d	Aircraft-type code (See Table A-2)
e	Airline identifier (See Table A-3)
f	Separation in nautical miles between this and the following aircraft
g	Time over the runway threshold (Greenwich Mean Time)
h	Runway exit time (Greenwich Mean Time)
i	Runway occupancy time in seconds
j	Exit number used
k	Runway "other use" code; this code is "1" if the runway was used for crossing by a taxiing aircraft or if there was a departure on a crossing runway after this arrival
l	Ceiling in hundreds of feet above ground level
m	Type of Ceiling O - Overcast B - Broken
n	Visibility in nautical miles
c	Obstructions to vision (if any) R - Rain F - Fog
p	Wind direction in degrees
q	Wind speed in knots
r	Runway condition 1 - Dry 2 - Wet
s	Interarrival time (between this and the next aircraft to land on this runway) in seconds
t	Trailing aircraft type (against which separation was measured)
u	Trailing aircraft type (against which interarrival time was measured)

```
ab  c   d  e  f    g        h        i   j  k l   m n o p   q  r s   t  u
||. |.. |. |. |... |....... |....... |.. |. | |..| |.| |.. |. | |... |. |.
L23 22  03 PI 5.25 13.30.00 13.30.38  38 08   0140 06  330 09 1  113 17 17
L23 22  17 GA 2.50 13.31.53 13.32.47  54 09   0140 06  330 09 1   87 02 02
L23 22  02 AA 2.75 13.33.20 13.34.09  49 11   0140 06  330 09 1   68 09 09
L23 22  09 NY 3.50 13.34.28 13.35.09  41 08 1 0140 06  330 09 1   97 09 09
L23 22  09 NY 4.00 13.36.05 13.37.01  56 11   0140 06  330 09 1  116 05 05
L23 22  05 EA 3.25 13.38.01 13.38.41  40 08   0140 06  330 09 1   93 06 06
L23 22  06 DL 8.00 13.39.34 13.40.17  43 08   0140 06  330 09 1  309 14 14
L23 22  14 GA 4.00 13.44.43 13.45.49  66 12   0140 06  330 09 1  128 09 09
L23 22  09 NY 3.00 13.46.51 13.47.25  34 08   0250 07  300 05 1   85 06 06
L23 22  06 DL 4.50 13.48.16 13.49.13  57 11 1 0250 07  300 05 1  119 07 07
L23 22  07 RZ 3.00 13.50.15 13.50.48  33 03   0250 07  300 05 1   78 09 09
L23 22  09 DL 2.50 13.51.33 13.52.30  57 11   0250 07  300 05 1   85 19 19
L23 22  19 IN 2.25 13.52.58 13.53.45  47 09   0250 07  300 05 1   56 09 09
L23 22  09 AL 4.00 13.53.54 13.54.36  42 08   0250 07  300 05 1  111 09 09
L23 22  09 AL 3.00 13.55.45 13.56.26  41 08   0250 07  300 05 1   81 03 03
L23 22  03 PI 3.00 13.57.06 13.57.43  37 07   0250 07  300 05 1   97 01 01
L23 22  01 EA 3.50 13.58.43 13.59.27  44 08   0250 07  300 05 1   80 06 06
L23 22  06 UA 3.75 14.00.03 14.00.49  46 08   0250 07  300 05 1  120 05 05
L23 22  05 EA 2.75 14.02.03 14.03.06  63 10   0250 07  300 05 1   79 02 02
L23 22  02 EA 3.50 14.03.22 14.04.03  41 08   0250 07  300 05 1  124 09 09
```

FIGURE A-1
ARRIVAL DATA BASE SAMPLE

TABLE A-2
AIRCRAFT TYPE CODES

1	A300
2	B727
3	B737
4	B747
5	B757
6	B767
7	DH7
8	F28
9	DC9
10	DC10
11	L1011
12	BAC111
13	DH6
14	Business Jet (Lear, Citation, Gulfstream, etc.)
15	Shorts 330
16	Convair 440, YS11, MU2
17	Light Twin
18	F27
19	B99
20	Convair 580
21	Swearingen Metroliner
22	DC6
23	DC3
24	L188 (Lockheed Electra)
25	DC8, B707
26	Single Engine

TABLE A-3
AIRLINE CODES

AA	American Airlines	NY	New York Air
AC	Air Canada	OW	National Air
AL	US Air	OZ	Ozark
AT	Arthur	PA	Pan Am
BA	British Airways	PE	Peoples Express
BN	Braniff	PI	Piedmont
CK	Liberty	PM	Pilgrim
CO	Continental	PT	Provincetown-Boston
DD	Command	QB	Quebecair
DL	Delta	QH	Air Florida
EA	Eastern	QO	Bar Harbor
EJ	New England	RC	Republic
EP	Empire	RP	Precision
ER	Emery	RZ	Ransome
FE	Federal Express	SM	Summit
FL	Frontier (and Frontier Horizon)	SS	Brockway
FR	Susquehanna	TV	Transamerica
FT	Flying Tigers	TW	Transworld
GG	North American	UA	United
HV	Unknown	UR	Empire
IN	East Hampton Aire	WA	Western
JI	Gull	WC	World Airways
LH	Lufthansa	YW	Will's Air
ML	Midway	YX	Midwest Express
NA	Air Niagra	ZZ	Zantop
NO	Air North	4A	Atlantic Air
NW	Northwest Orient	4M	Island Air

APPENDIX B
ACRONYMS

ATC	Air Traffic Control
ATCAC	Air Traffic Control Advisory Committee
ATIS	Automatic Terminal Information Service
BOS	Boston Logan International Airport
BRITE	Bright Radar Indicator Terminal Equipment
CPU	Central Processing Unit (Computer)
DC9	Douglas Aircraft DC9 Commercial Jet Aircraft
EWR	Newark International Airport
FAA	Federal Aviation Administration (U.S. Department of Transportation
FORTRAN	Formula Translater Programming Language
GTOW	Gross Takeoff Weight
HS25	Hawker-Siddeley MS25 Business Jet
IAT	Interarrival Time
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LGA	La Guardia Airport
nmi	nautical miles
PANYNJ	Port Authority of New York and New Jersey
ROT	Runway Occupancy Time
VMC	Visual Meteorological Conditions

APPENDIX C
REFERENCES

1. A. L. Haines, R. M. Harris, and A. N. Sinha, "Operational Techniques for Increasing Airport Capacity," The MITRE Corporation, Metrek Division, MP-82W24, October 1982.

2. W. J. Swedish, "Evaluation of the Potential for Reduced Longitudinal Spacing on Final Approach", The MITRE Corporation, Metrek Division, FAA-EM-79-7, MTR-79W00280, August 1979.